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VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Blacksburg, Virginia 24061

Nonlinear Wave Choked Inlets

Semiannual Progress Report

Period: October 1, 1978 - April 30, 1979

The two basic changes that were done to the quasi-one dimensional flow program, where the replacement of the Runge-Kutta subroutine with a subroutine using a modified divided difference form of the Adams Pece Method and the replacement of the matrix inversion routine with a pseudo-inverse routine. The following system of first-order differential equations is solved in the program:

$$A \frac{dy}{dx} = B, \text{ where } A \text{ is a } n \times n \text{ matrix,}$$

y and B are n -component column vectors.

At the throat of the duct, if the flow is approaching choked conditions then $\det A \rightarrow 0$ and the system is singular. The pseudo-inverse routine determines, towards the solution of the linear system $AZ = B$, the singular value decomposition, $A = USV^T$. Householder bidiagonalization and a variant of the QR algorithm are used. The output from this routine is S , V , and G , where $G = U^T B$; S is diagonal and V, U are orthogonal; S also determines whether A is singular. If one or more of the elements of S is zero then A is singular. In the subroutine, if $S_{ii} \leq 10^{-14}$ then S_{ii}^{-1} is set equal to zero. The program then solves the following system

$$SV^T \frac{dy}{dx} = U^T B = G$$

$$V^T \frac{dy}{dx} = S^{-1} G = S_{ii}^{-1} G_i$$

(NASA-CR-158691) NONLINEAR WAVE CHOKED
INLETS Semiannual Progress Report, 1 Oct.
1978 - 30 Apr. 1979 (Virginia Polytechnic
Inst. and State Univ.) 9 p HC A02/MF A01



N79-25343

Unclass

CSCL 20D G3/34 22260

If $\frac{G_i}{S_{ii}} \geq 100$ the program stops since this indicates that y' is becoming too large for the integration routine to handle. Therefore incompatible reflection coefficients (c_R 's) have been chosen. If the above check is passed, then y' is integrated. Solving for y' we have

$$y' = VS^{-1}G$$

Now these values are passed to the integration routine. Unlike the Runge-Kutta routine which would integrate to the end of the duct even if incorrect c_R 's were input, the present routine will not pass through the throat. The first cases considered were for one reflection coefficient where

$$\rho_{11}^L(0) = c_R \rho_{11}^R(0), \text{ and } c_R \rho_{11}^R(0)$$

were specified. The initial conditions at $x = 0$ for the higher harmonics were set equal to zero.

By varying c_R the following plot was obtained showing the region of correct c_R 's. This region was determined using two harmonics. Later cases using four and ten harmonics indicated that the region did not shrink by much.

The following examples compare the original Runge-Kutta version of the program with the modified version with the Adams-Peace and pseudo-inverse subroutines. The input to both runs is identical except for the c_R 's. For the Runge-Kutta case, $c_R = (0., 0.)$ and the results are for two cases, two and four harmonics. It is seen that as the throat is approached $\det A \rightarrow 0$ and there is a substantial growth in the amplitudes of the harmonics. In the case of four harmonics there are very large jumps in the amplitudes near the throat. This indicates that incorrect c_R 's were chosen.

The example using the modified program was run with $c_R = (-.5, -3.3)$. As is seen there are no large oscillations in the harmonics near the throat. This implies that the integration to the right end is valid. In the former cases, the Runge-Kutta routine could not detect the singularity and was integrating across it. Therefore, the values obtained by the Runge-Kutta method in the vicinity of the throat to the right end are incorrect. If this occurs in the new version, it will terminate at the throat where

$$RU_n = U_{1n} - \frac{C_0}{\rho_0} \rho_{1n}$$

$$RT_n = T_{1n} - \frac{(\gamma-1)T_0}{\rho_0} \rho_{1n}$$

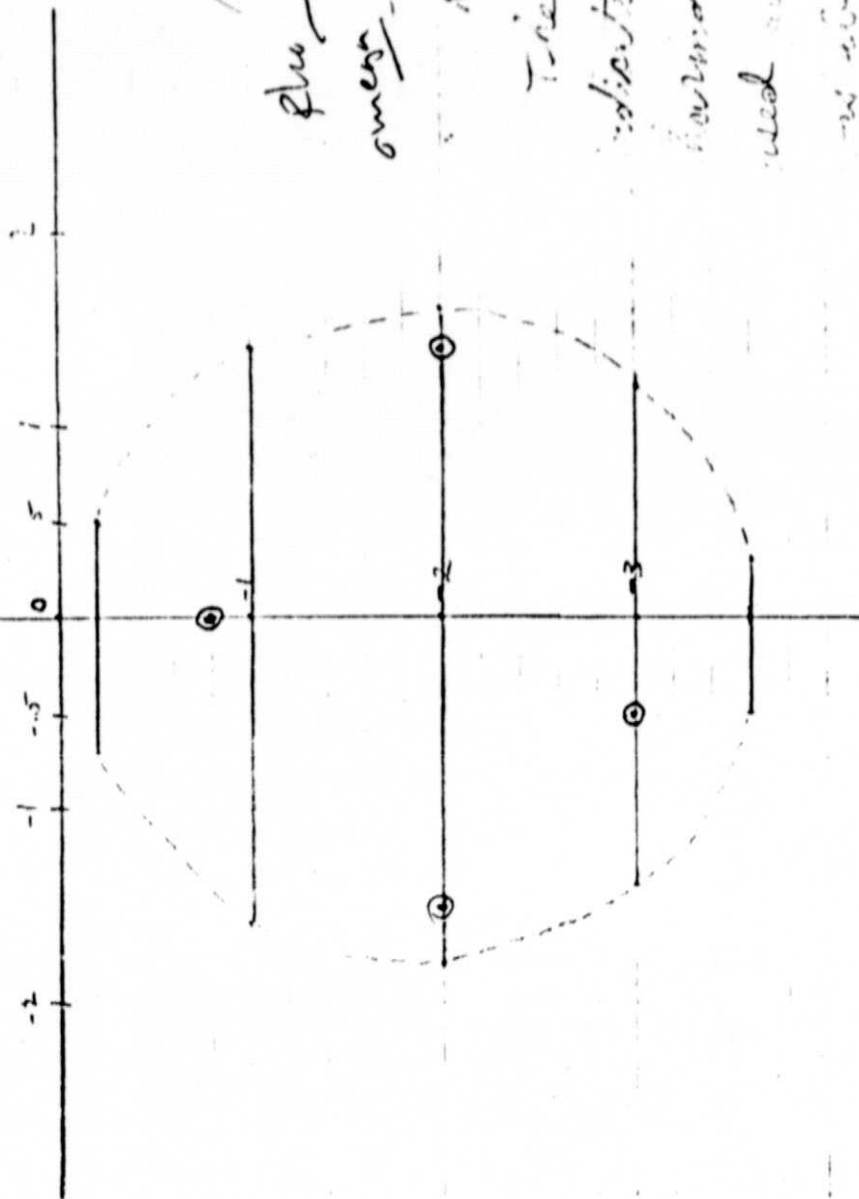
$$\omega = 1$$

$$M_0 = -.4$$

$$\rho_I = .005$$

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$\text{Im}(s)$



$\text{Re}(s)$

$$M_g = 0.2$$

$$\phi_{wo} f_I = 0.005$$

$$\omega_{max} = 1$$

$$N_H = 2$$

The root loci
indicate that
harmonic oscillations
will be present
and the system
will be stable to
integrate through
the duct.

NUMBER OF HARMONICS CONSIDERED= 4

W= 1.000 XMC0=-0.4000 XF= 2.000 A2= 0.100 DD= 1.000
 CR= -0.5000 -3.3000 RI= C.0050 NX= 80 NXI= 80 XMU= 0.0

X	X/L	DET	MACH	FIRST HARMON.	SECOND HARMON.	THIRD HARMON.	FOURTH HARMON.
0.02500	0.00302	0.250	-0.40030	0.98584	0.00043	0.00001	0.00000
0.05000	0.00604	0.270	-0.40120	0.98584	0.00043	0.00001	0.00000
0.07500	0.00906	0.240	-0.40271	0.98584	0.00043	0.00001	0.00000
0.10000	0.01208	0.210	-0.40484	0.98584	0.00043	0.00001	0.00000
0.12500	0.01510	0.180	-0.40759	0.98584	0.00043	0.00001	0.00000
0.15000	0.01812	0.140	-0.41096	0.98584	0.00043	0.00001	0.00000
0.17500	0.02115	0.100	-0.41496	0.98584	0.00043	0.00001	0.00000
0.20000	0.02417	0.060	-0.41950	0.98584	0.00043	0.00001	0.00000
0.22500	0.02719	0.020	-0.42489	0.98584	0.00043	0.00001	0.00000
0.25000	0.03021	0.000	-0.43084	0.98584	0.00043	0.00001	0.00000
0.27500	0.03323	0.000	-0.43747	0.98584	0.00043	0.00001	0.00000
0.30000	0.03625	0.000	-0.44477	0.98584	0.00043	0.00001	0.00000
0.32500	0.03927	0.000	-0.45277	0.98584	0.00043	0.00001	0.00000
0.35000	0.04229	0.000	-0.46147	0.98584	0.00043	0.00001	0.00000
0.37500	0.04531	0.000	-0.47089	0.98584	0.00043	0.00001	0.00000
0.40000	0.04833	0.000	-0.48105	0.98584	0.00043	0.00001	0.00000
0.42500	0.05135	0.000	-0.49195	0.98584	0.00043	0.00001	0.00000
0.45000	0.05437	0.000	-0.50360	0.98584	0.00043	0.00001	0.00000
0.47500	0.05739	0.000	-0.51602	0.98584	0.00043	0.00001	0.00000
0.50000	0.06042	0.000	-0.52922	0.98584	0.00043	0.00001	0.00000
0.52500	0.06344	0.000	-0.54319	0.98584	0.00043	0.00001	0.00000
0.55000	0.06646	0.000	-0.55794	0.98584	0.00043	0.00001	0.00000
0.57500	0.06948	0.000	-0.57347	0.98584	0.00043	0.00001	0.00000
0.60000	0.07250	0.000	-0.58979	0.98584	0.00043	0.00001	0.00000
0.62500	0.07552	0.000	-0.60685	0.98584	0.00043	0.00001	0.00000
0.65000	0.07854	0.000	-0.62466	0.98584	0.00043	0.00001	0.00000
0.67500	0.08156	0.000	-0.64320	0.98584	0.00043	0.00001	0.00000
0.70000	0.08458	0.000	-0.66241	0.98584	0.00043	0.00001	0.00000
0.72500	0.08760	0.000	-0.68225	0.98584	0.00043	0.00001	0.00000
0.75000	0.09062	0.000	-0.70264	0.98584	0.00043	0.00001	0.00000
0.77500	0.09364	0.000	-0.72350	0.98584	0.00043	0.00001	0.00000
0.80000	0.09666	0.000	-0.74463	0.98584	0.00043	0.00001	0.00000
0.82500	0.09969	0.000	-0.76601	0.98584	0.00043	0.00001	0.00000
0.85000	0.10271	0.000	-0.78723	0.98584	0.00043	0.00001	0.00000
0.87500	0.10573	0.000	-0.80796	0.98584	0.00043	0.00001	0.00000
0.90000	0.10875	0.000	-0.82766	0.98584	0.00043	0.00001	0.00000
0.92500	0.11177	0.000	-0.84543	0.98584	0.00043	0.00001	0.00000
0.95000	0.11479	0.000	-0.86190	0.98584	0.00043	0.00001	0.00000
0.97500	0.11781	0.000	-0.87715	0.98584	0.00043	0.00001	0.00000
1.00000	0.12083	0.000	-0.89154	0.98584	0.00043	0.00001	0.00000
1.02500	0.12385	0.000	-0.90508	0.98584	0.00043	0.00001	0.00000
1.05000	0.12687	0.000	-0.91787	0.98584	0.00043	0.00001	0.00000
1.07500	0.12989	0.000	-0.92997	0.98584	0.00043	0.00001	0.00000
1.10000	0.13291	0.000	-0.94145	0.98584	0.00043	0.00001	0.00000
1.12500	0.13593	0.000	-0.95224	0.98584	0.00043	0.00001	0.00000

NUMBER OF HARMONICS CONSIDERED= 2

[illegible]

THIRD
FLOOR.

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	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ	CA	CB	CC	CD	CE	CF	CG	CH	CI	CJ	CK	CL	CM	CN	CO	CP	CQ	CR	CS	CT	CU	CV	CW	CX	CY	CZ	DA	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	DO	DP	DQ	DR	DS	DT	DU	DV	DW	DX	DY	DZ	EA	EB	EC	ED	EE	EF	EG	EH	EI	EJ	EK	EL	EM	EN	EO	EP	EQ	ER	ES	ET	EU	EV	EW	EX	EY	EZ	FA	FB	FC	FD	FE	FF	FG	FH	FI	FJ	FK	FL	FM	FN	FO	FP	FQ	FR	FS	FT	FU	FV	FW	FX	FY	FZ	GA	GB	GC	GD	GE	GF	GG	GH	GI	GJ	GK	GL	GM	GN	GO	GP	GQ	GR	GS	GT	GU	GV	GW	GX	GY	GZ	HA	HB	HC	HD	HE	HF	HG	HH	HI	HJ	HK	HL	HM	HN	HO	HP	HQ	HR	HS	HT	HU	HV	HW	HX	HY	HZ	IA	IB	IC	ID	IE	IF	IG	IH	II	IJ	IK	IL	IM	IN	IO	IP	IQ	IR	IS	IT	IU	IV	IW	IX	IY	IZ	JA	JB	JC	JD	JE	JF	JG	JH	JI	IJ	JK	KL	JM	JN	JO	JP	JQ	JR	JS	JT	JU	JV	JW	JX	JY	JZ	KA	KB	KC	KD	KE	KF	KG	KH	KI	KJ	KK	KL	KM	KN	KO	KP	KQ	KR	KS	KT	KU	KV	KW	KX	KY	KZ	LA	LB	LC	LD	LE	LF	LG	LH	LI	LJ	LK	LL	LM	LN	LO	LP	LQ	LR	LS	LT	LU	LV	LW	LX	LY	LZ	MA	MB	MC	MD	ME	MF	MG	MH	MI	MJ	MK	ML	MM	MN	MO	MP	MQ	MR	MS	MT	MU	MV	MW	MX	MY	MZ	NA	NB	NC	ND	NE	NF	NG	NH	NI	NJ	NK	NL	NM	NN	NO	NP	NQ	NR	NS	NT	NU	NV	NW	NX	NY	NZ	OA	OB	OC	OD	OE	OF	OG	OH	OI	OJ	OK	OL	OM	ON	OO	OP	OQ	OR	OS	OT	OU	OV	OW	OX	OY	OZ	PA	PB	PC	PD	PE	PF	PG	PH	PI	PJ	PK	PL	PM	PN	PO	PP	PQ	PR	PS	PT	PU	PV	PW	PX	PY	PZ	QA	QB	QC	QD	QE	QF	QG	QH	QI	QJ	QK	QL	QM	QN	QO	QP	QQ	QR	QS	QT	QU	QV	QW	QX	QY	QZ	RA	RB	RC	RD	RE	RF	RG	RH	RI	RJ	RK	RL	RM	RN	RO	RP	RQ	RR	RS	RT	RU	RV	RW	RX	RY	RZ	SA	SB	SC	SD	SE	SF	SG	SH	SI	SJ	SK	SL	SM	SN	SO	SP	SQ	SR	SS	ST	SU	SV	SW	SX	SY	SZ	TA	TB	TC	TD	TE	TF	TG	TH	TI	TJ	TK	TL	TM	TN	TO	TP	TQ	TR	TS	TT	TU	TV	TW	TX	TY	TZ	UA	UB	UC	UD	UE	UF	UG	UH	UI	UJ	UK	UL	UM	UN	UO	UP	UQ	UR	US	UT	UU	UV	UW	UX	UY	UZ	VA	VB	VC	VD	VE	VF	VG	VH	VI	VJ	VK	VL	VM	VN	VO	VP	VQ	VR	VS	VT	VU	VV	VW	VX	VY	VZ
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